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ABSTRACT

Reported are results from a pilot study evaluating the effectiveness of a high school mathematics course on the applications of proportional calculations for students subsequently enrolled in chemistry. Two effects were investigated: (1) the effect of the course on students' ability to do proportional calculations not explicitly involving chemical concepts and terms, and (2) the effect on students' performance in a regular secondary school chemistry course. Also investigated was whether there is a relationship between ability to do proportional calculations and Piagetian cognitive level. Results indicate that the course was effective in increasing students' ability to solve everyday problems, but that there was no difference in problem-solving ability of students who had taken the course. Results of the Piagetian investigation indicate that students can be taught to solve both concrete and formal proportional calculations independent of their cognitive level when the variables are familiar to the students. (CS)

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A Pre-Chemistry Course on Proportional Calculations

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The Science-Math Project undertook the development, teaching, and assessment of a course on the applications of proportional calculations needed by secondary students to study chemistry and physics. The study was conducted in the Spring of 1978 at a high school in a small city in Connecticut. The students in this study were predominantly children of blue collar workers in a largely white population. Of the 1979 graduating class at this high school, 69% of the 273 students intended to go on to further schooling and 37% of the total graduates were planning to go to a four-year college.

The sample for the study was drawn by random selection of sections of non-honors students taking college-bound biology. There were four experimental sections and four control sections. Three of the experimental sections were taught by the director of the project, a college teacher of chemistry, while the fourth was taught by an experienced secondary chemistry teacher. The course was given for half-time during the Spring semester as an additional required course for the experimental group. Those students in the experimental sections who planned to take chemistry the following year were followed in our study.

The curriculum was written prior to the field-test; later parts were modified and rewritten before instruction based on feedback from the first part of the course. Most of the problems in the text dealt with everyday consumer and vocational variables with which the students were familiar with the exception of some chemistry problems inserted as "nonsense" problems. The topics covered were: introduction to proportions including the unary rate, units analysis--also known as dimensional analysis, factor-label method, and quantity calculas--, rate equations, ratios and percentages, the inverse proportion, and introduction to graphs. Six experiments using familiar materials in a novel way were also included.

A goal of close to 100% achievement was set for the first part of the course. To achieve this took longer than was expected so some of the latter part of the course was not completed by most of the sections.

The most important innovation in the development of the curriculum was the unary rate strategy which evolved during classroom instruction based upon student feedback. The unary rate was a term we adopted to describe the rate per one of a variable, such as miles per one hour or cost per one hamburger. The unary rate strategy was simply that if you know how much per one of a given quantity, then you can find out how much for any multiple of that quantity. Thus, if you pay 75¢ per hamburger, then for 8 hamburgers you will pay eight times as much. This turned out to be the strategy most logical to the students and, eventually, became the primary strategy used in our teaching.

Two effects were investigated in this project, with corresponding null hypotheses. They were:

(1). The effect of the course on student's ability to do proportional calculations not explicitly involving chemical concepts and terms.

(2). The effect of the course on the students' subsequent performance in a regular secondary school college-preparatory chemistry course.

The relationship between the ability to do proportional calculations and Piaget level was also investigated.

To determine whether the control and experimental groups were statistically equivalent, t-test comparisons were made of the differences in the means in test scores between the two groups. These tests included five given by the Project and three from student records. The groups did not differ significantly. They also did not differ significantly on any of the curriculum pre-test questions.

Measure of the student's ability to do proportional calculations not explicitly involving chemical concepts and terms was based on a test given before the course as a pre-test, and in a matched version given after the course as a post-test. A description of the pre-test will be given later. An analysis of variance was carried out using the procedure developed by Lindquist (Design and Analysis of Experiments in Psychology and Education by E. F. Lindquist, Houghton Mifflin Co., Boston, 1953, pages 172-177) in which the experimental unit is the class rather than the student. Table 1 summarizes the results for the analysis of variance of means of differences in the pre-test and post-test scores. The null hypothesis that there was no difference in the change of achievement in proportional problem-solving due to taking the Science-Math Course was rejected at the 1% level of significance. We conclude that the course was successful in teaching proportional calculations to the experimental group.

It should be recognized that this was essentially a pilot study which is now in the process of being replicated on a larger scale. Several of the questions used on the pre-test showed a ceiling effect; there was little gain possible on these questions because scores on the pre-test were already high. Such questions tended to be rote types. Also, there was little gain on topics near the end of the curriculum primarily because most sections studying the Science-Math course never got to them. Had more time been available for the course and had questions with a ceiling effect been omitted, the improvement in scores on a test of proportional calculations after the Science-Math course might have been greater than they were in the study. Table 2 presents an overview of the pre-test; it describes the question by type and range of pre-test scores for the combined experimental and control groups. The classification by score into three cognitive levels suggests a hierarchy of comprehension of proportional problem-solving. The lowest cognitive level, with the highest achievement

Table 1. Analysis of Variance of Pre- and Post-Test Differences in Total Scores Between the Experimental and Control Group

MEAN SCORES	EXPERIMENTAL	CONTROL
Pre-Test	5.337	5.000
Post-Test	7.833	5.325

Source	Sum of Squares	Degrees of Freedom	Mean Square	F-Test	Significance
Group	85.110	1	85.110	15.776	0.008
Section	32.369	6	5.395	1.607	0.159
Student	228.351	68	3.358		
Total	345.830	75	4.611		

Table 2. Classification by Score on Each Science-Math Pre-Test Question* (Procedure Correct)

Question group by score	Mean Scores (on each item)	Question Number	Type of Question	Cognitive Group Type
Easy, 2/3 or more of 55 have it correct	0.895	4	Rate-ratio	Low cognitive
	0.776	2	Additive	
	0.671	11	Algebra, symbols only	
Middle, between 1/3 and 2/3 correct	0.658	6	Percentage	Middle cognitive or transitional
	0.618	3	Algebraic, labeled numbers	
	0.500	1	One-step proportion, word distractors	
	0.487	8	One-step proportion with picture (similar to Stickman)	
Difficult, less than 1/3 correct	0.329	7	Five-step proportion, one rate inversion information organized	Upper cognitive
	0.171	5	Two-step word proportion	
	0.158	9	Equation from data	
	0.066	10	Inversion proportion	

* Question 2, was an exploratory question on additive reasoning in a problem of constant differences. Such problems were not taught in the Science-Math course.

includes rate problems. The highest cognitive level includes problems with more than one step or else includes the inverse proportion. A correspondence with Piaget level suggests itself but is, of course, only speculative without further testing.

The second effect investigated concerned transfer to achievement in chemistry for those students who had been in the study and went on to take chemistry. Since the quantitative part of the course in chemistry at this particular high school was given during the first semester, we examined the quantitative questions included in the mid-year examination. The null hypothesis was that there was no significant difference in setting up the correct expressions for solving quantitative problems between students who had taken the experimental course and those who had not. Table 3 presents the ANOVA on achievement on problems. The hypothesis is accepted since the significance did not reach 5%. However, the difference was sufficiently close to significance to encourage replication of the study with an improved curriculum and a longer period of study.

Another question investigated was whether there is a relationship between ability to do proportional calculations not explicitly involving chemical concepts and terms and Piaget level. The measure of Piaget cognitive level was a sum of the Gray Test of Logical Reasoning for combinations and control of variables, and the Stickman test of proportional reasoning. These tests were given before the Science-Math course for both the experimental and control groups. One concrete and two formal cognitive levels based on the scores were calculated for the control and experimental groups. The null hypothesis was that there was no relationship between Piaget level and level of achievement on the post-test for both the experimental and control group.

Table 3. Analysis of Variance Table Comparing Experimental and Control Groups for Correct Dimensional Analysis in Stoichiometry Problems

Source	Sum of Squares	Degrees of Freedom	Mean Square	F-Test	Significance
Group	11.068	1	11.068	5.425	0.059
Section	12.240	6	2.040	0.526	Over 0.5
Student	240.628	62	3.881		
Total	263.931	69	3.825		

The strength of the linear relationship between Pagetian reasoning and achievement on the post-test was estimated by Spearman's rank correlation coefficient corrected for ties, using a t distribution (Siegel p. 212). The results are shown in Table 4.

Table 4. Relationship Between Piaget Reasoning and Achievement on Post-Test

	Control	Experimental
Degree of Freedom, n-2	38	34
Correlation	0.744	0.257
t	6.87	1.55
Critical region for two-tailed test	t> 3.65 at 0.001	t> 2.02 at 0.05
Significance	Less than 0.1%	Greater than 5%

A significant relationship between Piagetian reasoning and achievement appears for the control group but not for the experimental group. This suggests that studying the Science-Math course helped the students with lesser ability to improve in achievement on problems of proportional calculations.

To investigate further the relationship between Piaget level and achievement, achievement on the post-test for the experiment and control groups were compared for the students at the three Piagetian levels of concrete, lower formal, and upper formal. The results are shown in Table 5.

Table 5. Post-Test Scores of Experimental and Control Groups for Students at Three Piagetian Levels

Post-Test Score	Piaget Score < 8 Concrete		8 ≤ Piaget Score ≤ 10 Lower Formal		Piaget Score > 10 Upper Formal	
	Control	Experimental	Control	Experimental	Control	Experimental
0						
1						
2	2					
3	5		2			
4	1	2	7	1	1	
5	2		3	2	1	
6		1	1		2	1
7	1		1	6	3	2
8		2		5	5	
9		2		2	2	2
10		1		3	1	
11		1		1		2
N	11	9	14	20	15	7
Mean	3.64	7.67	4	7.75	7.33	8.57

The difference in achievement on the post-test between the experimental and control groups at the three Piagetian levels was tested using the Mann-Whitney U Statistic. (Siegel, p. 119). The results are summarized in Table 6.

Table 6. Differences in Achievement in the Post-Test Between Experimental and Control Groups at Various Piagetian Levels.

	Control		Experimental			
	Sum of Ranks	N	Sum of Ranks	N	U	Significance
Concrete	74	11	136	9	8	Less than 0.1%
Lower Formal	123.5	14	471.5	20	18.5	Less than 0.1%
Upper Formal	155	15	98	7	35	Greater than 5%

From these tests the null hypothesis of no difference in achievement between the experimental and control groups is rejected for students at the concrete and lower formal levels, but not at the upper formal.

Hence, we see that the Piaget concrete and lower formal students showed significant improvement in achievement in proportional calculations as a result of the course while the upper formal students did not. It needs to be pointed out that not all sections of students finished the Science-Math curriculum. Perhaps study of the last chapters which contained more advanced materials might have significantly improved the achievement of the upper formal students.

Ref.: Non-parametric Statistics for the Behavioral Sciences, by Sidney Siegel, McGraw-Hill Book Company, New York, 1956.